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SIR-C/X-SAR: A Multifaceted Radar

F. Stuhr, R. Jordan, M. Werner

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109

INTRODUCTION

International cooperation by the U.S., Germany and Italy produced the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) system, which successfully flew aboard the Shuttle *Endeavour* in April 1994 and again in October 1994. The SIR-C/X-SAR mission objectives are to carry out specific scientific investigations over the entire Earth relative to ecology, hydrology, geology, and oceanography. The international SIR-C/X-SAR Science Team includes fifty-two members, selected from thirteen countries and twenty-five universities. These scientists, supported by various participants, performed extensive ground truth measurements around the world during the flights.

The international use of spaceborne imaging SARs for long-term Earth observation has dramatically increased over the past five years. The European Space Agency (ESA) Remote Sensing Satellite (ERS-1) and ERS-2 C-band SARs were launched in 1991 and in April 1995, respectively. The National Space Development Agency (NASDA) of Japan Earth Resources Satellite (JERS-1) L-band SAR was launched in 1992. In September 1995, the Canadian Space Agency is scheduled to launch RADARSAT, a C-band SAR with a number of modes for selectable pointing, resolution, and ground coverage. ESA is also planning to launch an Environmental Satellite (ENVISAT) in 1998, which will be a C-band SAR with an active phased array antenna and two polarizations. Russia is planning the ALMAZ Mission, which is an S-band SAR with mechanical beam steering.

Fig. 1 shows the SIR-C/X-SAR system during the second flight as viewed from the Shuttle crew cabin. This system is the world's first spaceborne multifrequency, multipolarization imaging radar and is unique in a number of ways. Interferometric processing will be possible at all three frequencies, using repeat-track data. SIR-C utilized an active phased array antenna for electronic beam steering and beam shaping, as well as operation in a scanning or dwell mode. SIR-C was developed for NASA by the Jet Propulsion Laboratory (JPL). The SIR-C antenna panels and associated electronics were provided by Ball Aerospace Corporation under contract with JPL. X-SAR was developed for the German and Italian space agencies by the German Aerospace Establishment (DLR) and the companies of Dornier in Germany and Alenia Spazio in Italy.

SIR-C is a major step forward in the series of NASA spaceborne imaging radar missions that began with Seasat in 1978 [1] and continued in 1981 with SIR-A and in 1984 with SIR-B [2], each managed by JPL. Each of these predecessors to SIR-C was an L-band SAR with a single polarization and a passive array antenna. Seasat flew at an 800 km altitude with a fixed 20-deg look angle. SIR-A and SIR-B flew modified Seasat radar equipment aboard the Shuttle with SIR-B having a mechanically steerable antenna.

MISSION OVERVIEW

The SIR-C/X-SAR mission consisted of a 10-day flight in April and a second 10-day flight in September/October 1994. The orbit inclination for the SIR-C flights was 57 deg. The Shuttle altitude of 225 km allowed a slight westward drift in the equatorial crossing longitude in its near one-day repeat orbit to capture data from the radar sites over a broad range of incidence angles and aspect angles. Data "takes" were largely over experiment sites selected prior to launch, with some in flight "targets of opportunity".

The orbital altitude was trimmed for the last three days of the second flight in order to provide the appropriate geometry for repeat-track interferometric data from day to day and over the six months between flights. The second flight provided the opportunity for assessment of change with time due to seasons and other factors. A total of 143 hours (93 terabits) of SAR data were digitally tape-recorded aboard the Shuttle for the two flights for subsequent processing at JPL and in Germany and Italy. Selected SAR data were downlinked via the Tracking and Data Relay Satellite System (TDRSS) to Houston operations and JPL for processing during the mission. The shuttle crew photographed many of the sites for subsequent comparison of optical and radar images.

FLIGHT SYSTEM OVERVIEW

Figure 2 is a block diagram of the SIR-C/X-SAR flight system aboard the Shuttle, consisting of five radars with numerous selectable modes and parameters. SIR-C operated at L-band and C-band using up to four simultaneous transmit/receive polarizations, while X-SAR operated at X-band using a single vertical polarization. The SIR-C active phased array antenna provided for electronic beam steering and beam shaping, including operation in a scanning (SCANSAR) or dwell (SPOTLIGHT) mode. The SIR-C SAR data collection was constrained by the Shuttle record rate of 180 Mbps, utilized by multiplexing four 45 Mbps channels. X-SAR had a single channel at 45 Mbps. The multiple elements of the phased array antenna, the redundancy in the sensor electronics, and the data routing flexibility gave SIR-C significant failure tolerance. The SIR-C/X-SAR system weighed approximately 20,000 pounds and used up to 9 Kw of Shuttle power when operating. While the SIR-C electronics equipment was conservative in construction, the overall radar capability was state-of-the-art.

The Shuttle interfaces included mechanical, power, timing, ground communication and data recording. The crew operated the three high-rate digital recorders located in the crew cabin to record all data on tape cassettes. The SIR-C/X-SAR three antennas were mounted as an array on a common support structure, with the array mechanical boresight tilted at 14 deg relative to the Shuttle. During data takes, the Shuttle was normally rolled 26 deg for an antenna look angle of 40 deg and was positioned tail forward or nose forward as required to provide coverage on either side of the ground track. The Shuttle performed yaw steering during data takes to maintain a manageable Doppler centroid offset by compensating for altitude variation and Earth's rotation, which was especially helpful for X-SAR.

RADAR SYSTEM MODES AND PARAMETERS

Multiple Frequencies and Polarizations

SIR-C and X-SAR were effectively five radars with regard to frequency and polarization. SIR-C operated at 1250 MHz (L-band) and 5300 MHz (C-band) with up to four simultaneous transmit/receive polarizations (VV, VH, HV, VV), while X-SAR operated at a single 9600 MHz (X-band) frequency with VV polarization. Table 1 summarizes the possible SIR-C frequency and polarization combinations and their utilization of the four 45 Mbps data channels. SIR-C required four physically separate RF transmit and receive channels for simultaneous operation at L-band and C-band, each using both vertical and horizontal polarizations. In order to operate dual-pol transmit at a given frequency, the vertical and horizontal pulses are staggered in time at one-half the interpulse period so as to separate the like and cross-pol echo returns. The standard data configuration provides a single 45 Mbps channel for a single frequency and polarization combination. The effective data rate is doubled for modes which provide two channels for a given frequency and polarization combination. The effective data rate is halved for the dual-frequency, quad-pol mode, where both like and cross-pol are time-multiplexed in a single channel.

The SIR-C/X-SAR range of radar sensitivity to surface roughness and radar signal penetration is extended by a factor of 8 over that of a single frequency system. Multiple polarizations enhance the radar backscatter sensitivity to target structure [3]. With the amplitude of four polarizations and the relative phase between them, the complete scattering matrix of a scene can be derived on a pixel-by-pixel basis. From the scattering matrix, all polarization responses can be generated during processing [4]. The active phased array provided the increased sensitivity required to detect weak cross-polarization echoes, while maintaining acceptable transmit power levels, due to the location of the transmit amplifiers and receivers next to the antenna radiating elements.

Transmit Pulse Characteristics

Both SIR-C and X-SAR could select a 10-MHz or 20 MHz transmit bandwidth. In addition, SIR-C could operate at 40 MHz. Increased bandwidth provided increased spatial resolution at the expense of swath width.

X-SAR had a single transmit pulse length of 40 μs, while SIR-C had 8.5, 17, or 33 μs. The longer pulse lengths provided increased the signal-to-noise ratio at the expense of Shuttle power.

Pulse Repetition Frequencies (PRFs) from 1240 to 1736 pulses per second were available for both SIR-C and X-SAR. One value was selected per data take for both SIR-C and X-SAR so that the imagery could be compared on a pixel-by-pixel basis. Lower PRFs allowed reduction of range ambiguities with wider swath, while the higher PRFs provided a higher signal-to noise ratio and reduced azimuth ambiguities. The selection of PRF also determined the position of the echo digitization window in the interpulse period.

Data Format

SIR-C could select 4 or 8 bits/word and X-SAR could select 4 or 6 bits/word. In addition, SIR-C could select a compression scheme known as (8,4) block floating point quantization. This provided an increased dynamic range at a data rate equivalent to the 4 bits/word format.

Antenna Pointing

Both the SIR-C and X-SAR boresights could be steered in 0.25-deg increments in the across-track (elevation) direction over ±20 deg relative to the nominal 40-deg look angle provided by Shuttle roll. This allowed flexibility of coverage for target areas located at varying distances from the Shuttle ground track. A 58-deg look angle was the maximum achievable with the minimum beamwidth due to range ambiguity limitations.

Antenna Beamwidth/ Swath Width

The X-SAR antenna had a fixed beamwidth of 5.5 deg in elevation and 0.14 deg in azimuth. The SIR-C antenna beamwidths in the azimuth direction were 1.0 deg at L-band and 0.25 deg at C-band. The SIR-C phased array provided for broadening of the beam in the elevation direction from its minimum 5-deg value. Seven SIR-C beam broadening values could be selected for an illumination beamwidth in elevation of up to 16 deg. The swath width actually achieved in the image is determined by the system data capacity to produce full range compression over the entire image sampled, as well as by the antenna illumination. After selection of the frequency/polarization mode, bandwidth, data format, and antenna boresight angle, a beam broadening value was selected to more optimally illuminate the target. This involved a trade between PRF and range and azimuth ambiguities. The maximum swath width achieved for X-SAR was 60 km and the maximum for SIR-C (without SCANSAR) was 90 km. The minimum swath width was 15 km for the SIR-C dual-frequency, quad-pol mode.

SIR-C/X-SAR Interferometry

Where the same target is imaged from slightly different positions, the SAR data can be interferometrically processed to determine terrain height [5]. This allows rectification of radar imaging distortions attributed to elevated features. Under certain conditions, repeat images also allow detection of terrain change with time in the radar direction with high precision (in the cm range). Data were collected during the two flights, which will allow repeat-track interferometric SAR processing at all three SIR-C/X-SAR frequencies. Interferometric baseline separations between repeat orbits of 10 to 4700 m were obtained. Day-to-day repeats were accomplished during the second flight as well as 6 mo repeats between flights.

SIR-C also had an along-track interferometric mode for detection of motion in the azimuth direction. This mode was achieved by operating the outermost C-band panels as separate antennas simultaneously.

RADAR SYSTEM PERFORMANCE

The key SIR-C/X-SAR system performance parameters are spatial resolution, ambiguities, impulse response sidelobes, sensitivity, dynamic range and polarization isolation. The perfomance values achieved during flight are summarized in Table II. During both missions in April and September of 1994, the SIR-C/X-SAR system performance exceeded all its requirements.

The spatial resolution is the width in meters of the system impulse response at the 3 dB points [6, 7]. While azimuth (along-track) resolution is stated as ground distance, range (across-track) resolution is stated as slant range distance. The slant range remains constant with incidence angle across the swath, while the surface resolution varies. The image quality of a picture element (pixel) is degraded by undesired outside energy which spills into the desired pixel. The primary contributors are range and azimuth ambiguities [8, 9] and energy outside of the mainlobe of the system impulse response [10]. The system sensitivity is the surface backscatter coefficient producing an echo signal strength equal to the system noise. The sensitivity varies with pulse duration, bandwidth, and incidence angle.

FLIGHT EQUIPMENT DESCRIPTION

Fig. 3 shows the SIR-C/X-SAR antenna and support structure being mated with the sensor electronics, which are installed on the Shuttle pallet. The sensor electronics included 10 major RF, digital and power distribution assemblies.

Antennas

Figure 4 shows the full SIR-C/X-SAR antenna array as well as one panel at each frequency. The three antenna physical apertures have the same along-track lengths of 12 m, which results in azimuth pattern beamwidths proportional to their wavelength. This allows selection of the same PRF for all three frequencies. They physically share the 4.2-m across-track dimension proportional to their wavelength, which results in approximately equal elevation pattern beamwidths.

The SIR-C L-band and C-band antennas were active phased arrays, consisting of panels containing the radiating aperture and the integrated transmit and receive electronics. The panel radiating aperture consisted of microstrip patch elements combined into subarrays, with each microstrip patch element shared by the vertical and horizontal polarization channels. Each L-band panel contained 9 subarrays in the across-track direction consisting of 6 elements along-track. The 9 subarrays were fed by 7 Transmit-Receive (T-R) modules for each polarization. The phase of each subarray could be independently controlled by a 4-bit phase shifter, which allowed steering in increments of 22.5 deg as well as shaping of the pattern. Each C-band panel was configured similar to L-band, except that it had 18 subarrays in the across-track direction consisting of 18 elements along-track. The 18 subarrays were fed by 14 T-R modules for each polarization. The across-track aperture dimensions were 2.9 and 0.7 m and the gains were 36.4 and 42.7 dB, respectively, at L-band and C-band.

The X-SAR antenna is a 12-m by 0.4 m slotted waveguide array with a specified gain of 44.5 dB. The antenna consists of 8 panels, each having fourteen resonant waveguides with 42 displaced slots. The X-SAR antenna is mounted to the common SIR-C/X-SAR truss and is mechanically steered in elevation to the selected incidence angle. The X-SAR antenna pattern is tapered in elevation, as is SIR-C, for reduced sidelobes and improved ambiguities.

RF Electronics

The SIR-C RF electronics drive the antenna distributed high-power amplifiers with chirp signals at L- and C-band frequencies for both H- and V-polarizations. The SIR-C chirp is a digitally generated tone, which is successively frequency stepped across the RF bandwidth over the pulse duration. The size of the steps were selected for a low phase error when correlated against an ideal linear FM signal. For the dual-pol transmit mode, the second polarization is transmitted with a delay of one-half the interpulse period relative to the first. The transmit pulse bandwidths (10, 20, or 40 MHz) and pulse lengths (8.5, 17, or 33 μs), were made feasible by the digital chirp generation.

The SIR-C return echoes from the antenna distributed low-noise amplifiers are downconverted in the RF electronics to four channels (LV, LH, CV, CH) of range offset video. For a dual-pol transmit mode, the receiver gain will be toggled to be low for the like-pol and high for the cross-pol echo. Each video output could be steered to any of the four digitizer input channels.

The X-SAR RF electronics uses two surface acoustic wave (SAW) devices to generate the 10- or 20-MHz bandwidth chirp pulses, which drive the transmitter. The high power amplifier (HPA) power supply, control, and protection devices are contained in a low voltage section. The traveling wave tube (TWT) amplifier is contained in a sealed container at 1 atmosphere of pressure. The peak TWT output power is 3.3 kilowatts and the overall HPA efficiency is 28 percent.

The X-SAR receiver gain is commandable from the ground or automatically controlled (AGC). The X-SAR receiver system, unlike SIR-C, incorporates quadrature receiver outputs to provide both I and Q outputs for data processing.

Digitizer and Formatter

Each of four SIR-C data channels accepts one of the four offset video channels from the SIR-C RF receivers, where each channel contains a frequency and polarization as defined in Table 1. Each channel is digitized, buffered, formatted and output at 45 Mbps to the routing electronics in the crew cabin. The output format is selectable as 8 bits/sample, 4 bits/sample, or (8,4) block floating point quantization (BFPQ). For BFPQ, data blocks of 128 samples of raw echo data are digitized to 8 bits/sample with uniform quantization. Subsets of 4 bits of each 8-bit sample are selected by a predetermined algorithm, effectively moving the "floating point" marker in binary data. The (8,4) BFPQ method provides an output rate similar to a 4-bit uniform system but with the dynamic range of an 8-bit system.

For X-SAR, analog I/Q data receivers are converted to digital form with either 4- or 6-bit converters. After time expansion and formatting, a serial data stream at 45 Mbps is provided by X-SAR to the routing electronics in the crew cabin.

Data Routing and Recording

All SIR-C and X-SAR data were recorded onboard the Shuttle by three high-rate digital recorders in the crew cabin. The data routing electronics in the crew cabin received a parallel 8-bit stream from each of the four SIR-C channels at 45 Mbps and multiplexed the data into a single parallel 8-bit channel at 180 Mbps for one of the onboard recorders designated for SIR-C. The serial X-SAR data stream was converted to parallel and recorded on the recorder dedicated to X-SAR. The data were recorded on tape cassettes, each storing up to 3.2×10^{11} bits. A total of 360 tapes were recorded during the two flights. It was also possible to route one of the SIR-C or X-SAR real-time input data channels or one of the recorder playback channels as a serial 45-Mbps data stream to the ground, using the Shuttle Ku-band link via the TDRSS.

Command, Timing, and Telemetry

Control of SIR-C/X-SAR during the mission was via commands uplinked from the ground through the Shuttle communication links. The SIR-C command sequencer stored up to 128 separate 512-bit commands in its onboard memory and executed them when their time tag matched the onboard clock. A stable local oscillator (STALO) in the RF electronics was used by the digital electronics to control SIR-C PRF changes, system mode receiver gain, exciter timing, digitized window position, and data channel switching, all of which changed state synchronously at 1-s intervals. SIR-C used an exact integer number of PRF pulses in one second to simplify the onboard timing. SIR-C also used PRFs for which there are integer number of 8-bit bytes in an echo range line to simplify the ground processing to images. Telemetry signals from the SIR-C assemblies were collected in the CITA and downlinked to the ground operations center.

The X-SAR digital electronics provided all X-SAR instrument interfaces, control, and monitoring. X-SAR was commanded separately from SIR-C. X-SAR timing was controlled by a clock, which was phased locked to the SIR-C STALO when both systems are operating synchronously. X-SAR was also capable of operating autonomously from its own timing.

RADAR GROUND PROCESSING

After each Shuttle landing, the SAR flight tapes were duplicated at JPL and the master stored. Duplicate X-band tapes were distributed to the processing facilities in Germany and Italy and duplicate SIR-C tapes were retained at JPL. Survey and precision processing will be accomplished using digital SAR processors specially developed by each country. Survey processing is done first, with reduced precision and fast throughput, to verify collection and select for further processing.

Using the Shuttle Ku-band downlink via the TDRSS during the flights, X-SAR produced X-band images in real time at Johnson Space Center (JSC) and JPL produced L-band and C-band images in near real time. These downlinks allowed end-to-end verification of all system components during the mission and provided limited products for public release.

REMOTE SENSING PRODUCTS

Delivery of full-quality products to the Science Team for investigation commenced in July 1994. It is expected to require about one year to complete full-quality products for the 143 hours (93 terabits) of SAR data. The results of scientific investigation using these products will be published by the Science Team. The discussion which follows does not present Science Team findings, but rather highlights the radar remote sensing utility as illustrated by SIR-C/X-SAR images. The black and white constraint on the imagery shown herein limits the ability to illustrate multifrequency and multipolarization characteristics, since most of the available SIR-C/X-SAR products use false color to highlight these backscatter signatures.

Topographic Mapping

The use of interferometric SAR to measure elevation is one of the most powerful capabilities of the radar. An interferometric pair of data (taken from closely spaced positions) is processed to form complex images; the image pair is combined to produce an interferogram (two-dimensional display of phase differences between the echoes); and the differences in phase are translated to elevation. The elevation data can be used to remove image distortion and produce a contour map. In addition, a three-dimensional image may be formed by placing the image pixels at the measured elevations. Fig. 5 illustrates this process using L-band images taken over Long Valley, California during the first and second flights with an interferometric baseline of 100 m. Although not a standard SIR-C product, a topographic map of Long Valley derived from the SIR-C interferogram is shown with elevation contour intervals of 50 m.

Absolute height measurement with meter-level accuracy requires knowledge of the length and attitude of the interferometer baseline to the 1 cm and 10 arc-sec levels, respectively. Since the Shuttle orbit for the two flights was only determined to tens of meters, known ground points are used to achieve accurate SIR-C/X-SAR topographic measurements. The SIR-C/X-SAR data will provide a basis for significant advancement of spaceborne interferometric techniques through assessment of various interferometric error sources, including temporal decorrelation. It is now clear that a properly equipped spaceborne interferometric

SAR system could produce a global digital elevat ion map, including cloud-covered areas, with 30-m resolution and 5-m accuracy. This could be done in significantly less time and al significantly lower cost than with other systems.

Geology

The radar sensitivity to physical shape and roughness makes it useful for geologic mapping of fault systems, alluvial fans, rock types, sail domes, volcanoes [1 1], lava flows, and a number of other features. Figure 6 shows the Kliuchevskoi volcano in Kamchatka, Russia, which erupted on September 30,1994 during the second SIR-C/X-SAR flight and provided a target of opportunity for photos and radar imaging. The Kamchatka volcanoes are very active and lie along the tectonic boundary where the Pacific plate is sinking beneath the Eurasian plate. This eruption spewed sulfur dioxide and ash up to 65,000 feet into the atmosphere, which the radar penetrated to reveal the volcanoes physical state. Figure 7 is a radar image in October 1994 at L-band and C-band of Mount Pinatubo in the Philippines, which erupted in June 1991. Mud flows were subsequently created during the monsoons and continue to spread and plague the area. Thousands of homes have been buried in mud and reck, forcing 80,000 people to flee the ma.

Figure 8 shows an extremely arrid area in southern Oman, which allows the radar signals to penetrate beneath the desert sand to reveal the underlying limestone and ancient drainage channels and riverbeds. The understanding of bow climate change impacts large land areas can be developed by studying structural features of the past [12]. This area contains the Lost City of Ubar discovered in 1992 through the use of remote sensing data.

Hydrology

Due to the high radar reflectivity of water, backscatter is sensitive to moisture content in soil and ground cover (i.e., vegetation, snow) as well as to free standing water [13, 14]. At the saint lime, the SIR-C/X-SAR multiple frequency capability allows varying degrees of penetration through vegetation, snow and ice. These capabilities allow sensing of moisture content in soil, vegetation and snow. Glacier accumulation and ablation can be estimated by distinguishing between the firn snow of accumulating areas and ablating glaciers beneath dry snow. Understanding moist ure content in in a region at lows determinat ion of major components of the large-scale hydrologic models, Such as how much precipitation is stored and how much runs off. In high lat itudes, seasonal snow cover is a major hydrologic storage component and dominates the runoff cycle. Glaciers are important indicators of climate history and change.

These same radar capabilities allow mapping of flooded areas [15], even those which are cloud-covered and have forest canopies. For lower radar frequencies, which penetrate to the tree trunks, the multiple polarization capability provides enhanced backscatter signature of flooding.

Vegetation Mapping

Radar backscatter is sensitive to the structure of trees and foliage. The SIR-C/X-SAR multiple frequencies extend the range of sensitivity to leaf sizes, branches, etc., since the backscatter is proportional to the size of objects in relation to the radar wavelength. In addition, the multiple polarizations provide increased sensitivity to tree and foliage structure. The lower frequencies can penetrate through much of a canopy to provide backscatter from the tree trunks. Estimations of forest biomass can be made [16] utilizing the returns over the SIR-C/X-SAR range of frequencies and polarizations. Dissipation and regrowth of forest and vegetation can be mapped.

The radar sensitivit y to moisture in the vegetation and soil is an important factor for vegetation state. Figure 9 shows a comparison between AIM ii 10, 1994 and October 1, 1994 of images in the boreal forest near Prince Albert in the Saskatchewan Province of Canada. This comparison highlights the radar sensitivity to foliage and to moisture in the soil and vegetation, which change due to spring thawing and the rainfall and dropping of leaves in the fall. The monitoring of seasonal changes is allows estimations of the rate of moisture evaporation and release of cadre dioxide into the atmosphere, which is critical to the global carbon cycle.

Oceanography

The radar is sensitive to the ocean surface roughness and structure, such as waves [1 7], currents [18] and eddies [19]. The surface features arc in turn an expression of subsurface internal waves and bottom topography. Figure 10 shows ice flows in the Weddel Sea in Antarctica, illustrating how the radar capabilities allow the classification and monitoring of sca ice. The differences in surface due, to heavy rainfall allow the detection and monitoring of sqalls. These arc important to global climate as well as navigation. Ships and their wakes arc easily discernible in radar imagery. oil spills can be detected and monitored duc to the smoothness of the waler in the spill area relative to the rougher surrounding ocean. In a German experiment during SIR-C/X-SAR, a "simulated" oil spill was detected at all three frequencies in the North Sea. In addition to radar imagery, the SIR-C/X-SAR along-track interferometry allows estimation of surface current sped.

Urban

Figure 11 is an image of Los Angeles, California during the second flight. The ocean and harbors arc at the bottom and the surrounding Hollywood Hills and San Gabriel Mountains toward the top. The freeways arc easily detected as dark lines as is the Los Angeles Airport bordering the ocean. Intermittent bright areas arc reflections from roofs, walls, and curbs, where streets and houses run parallel to the Shuttle track.

SUMMARY

SIR-C/X-SAR has produced a uniquely rich global radar data set for scientific and utilitarian assessment, which include multiple frequencies, polarizations, incidence angles, aspect angles and resolutions. Interferometric height measurement and use of SCANSAR were demonstrated. Through repeat passes and a repeat flight, a temporal view is available. The SIR-C/X-SAR results should contribute significantly to the international spaceborne imaging radar knowledge as a basis for future remote sensing endeavors.

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